# CALCULATION OF STRESS IN CAR SLING

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**Abstract:**
Methods of calculations of stress in individual parts of car slings are discussed. Special attention is given to welded slings which are considered rigid frames. Mathematical solution is carried out for three operational conditions: normal operation (running conditions), safety gear operation and buffer engagement. Load exerted upon each part of the car frame is depicted and bending moments along the frame are illustrated in each particular case.

## 1. INTRODUCTION

The car frame (car sling) forms the supporting steel structure of the car. It consists of (i) the crosshead beam(s), (ii) two vertical uprights, called stiles and (iii) the safety plank. The car sling is completed by bolting, riveting or welding the stiles to the crosshead at their upper end and to the safety plank at the bottom. It must be guided on each guide rail by upper and lower guiding members attached to the frame.

The car frame is most frequently of a side-post construction with guide rails located on two opposite sides. A diagram of this traditional side-post car frame is illustrated in Fig. 1. Brace rods in Fig. 1 extend from the elevator platform framing to the stiles for the purpose of supporting the platform and holding it securely in position.

The frame and its guiding members must be so designed to withstand the forces and moments imposed on them under all operational conditions.

Maximum allowable stresses in car frame and platform members and their connections are specified in national and/or international safety codes as well as maximum allowable deflections.

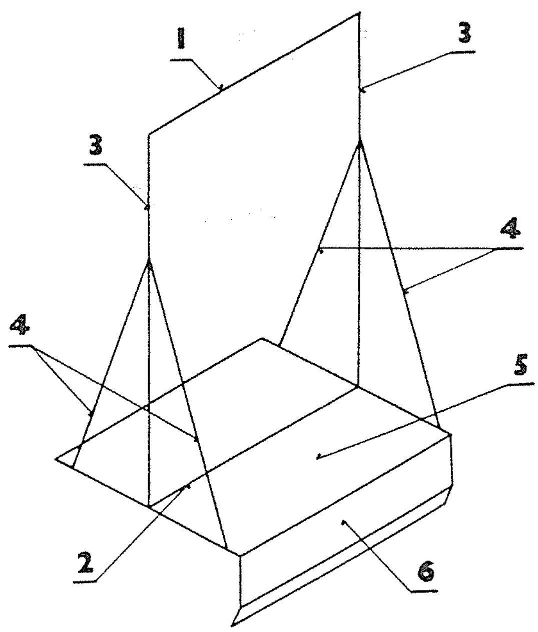



Fig. 1 - Side-post car frame.

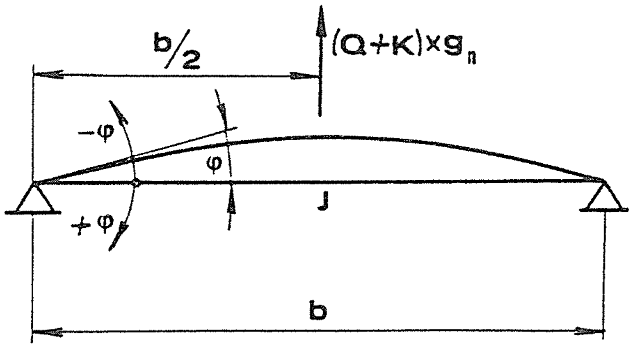
## 2. CALCULATION OF CAR FRAME

The formulae which will be presented here are valid for side-post car frames and platform members and reflect both the static and dynamic condition of the car frame components. For cars with corner-post frames, of the underslung-type or other special car frames and platform constructions the formulae for calculation of stress and deflection do not generally apply and should be modified to suit the special conditions in each case.

Welded car frames should be considered rigid frames and the calculation should be modified accordingly. The mathematical solution is based on the equality of angles of distortion of two frame components at the point of their jointing, e.g. the angle of distortion of the end of the crosshead beam must be equal to the angle of distortion of the upper end of the stiles, etc. The angle of distortion is identical with the angle of the tangent to the line of deflection of the beam and consequently it is given by the reaction force induced by the moment area, divided by the product $E \times J$. After the mathematical determination of inner moments in the corners of the car frame individual parts of the frame may be considered detached from the rest and calculated like simple beams.

The following cases may occur in the calculation:

*Simple beam, concentrated load in the middle of the span* (Fig. 2)
In Fig. 2 positive and negative directions of distortion are indicated.

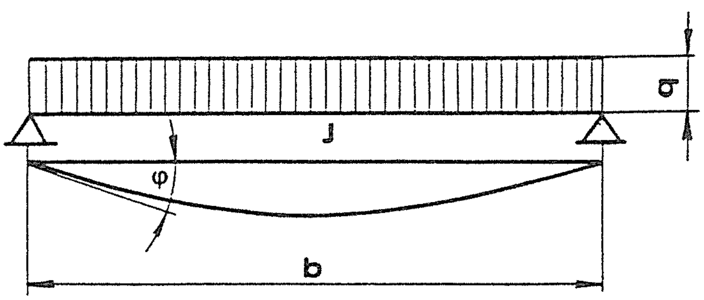



$$\varphi = - \frac{(Q + K) \times g_n \times b^2}{16 E \times J}$$

Fig. 2 - Diagram for calculation of the angle of distortion.

*Simple beam, uniformly distributed load* (Fig. 3)
The unit load is given by the formula:

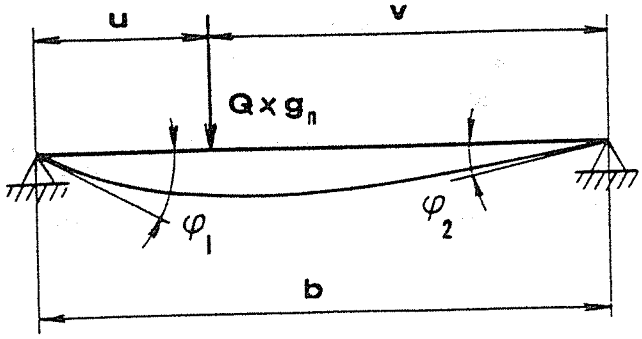
$$q = \frac{(Q + K) \times g_n}{b}$$




$$\varphi = \frac{(Q + K) \times g_n \times b^2}{24 E \times J}$$

Fig. 3 - Diagram for calculation of the angle of distortion.

*Simple beam, concentrated load in general position* (Fig. 4)

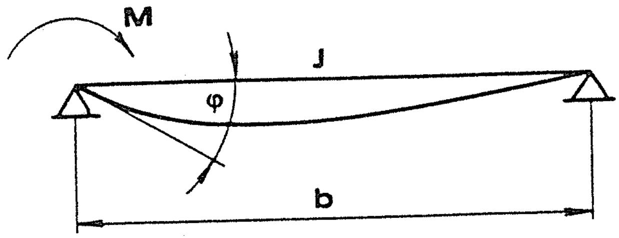



$$\varphi_1 = \frac{Q \times g_n \times v}{6b \times E \times J} \times (b^2 - v^2)$$

$$\varphi_2 = \frac{Q \times g_n \times u \times v \times (b + u)}{6b \times E \times J}$$

Fig. 4 - Diagram for calculation of the angle of distortion.

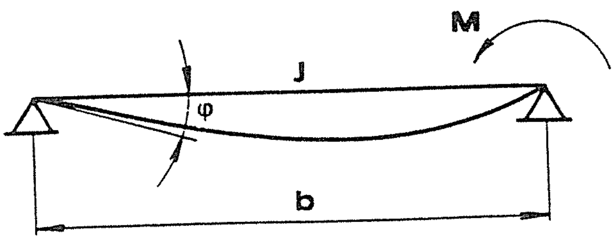
*Simple beam, inner moment at the end where the angle of distortion is calculated* (Fig. 5)




$$\varphi = \frac{M \times b}{3E \times J}$$

Fig. 5 - Diagram for calculation of the angle of distortion.

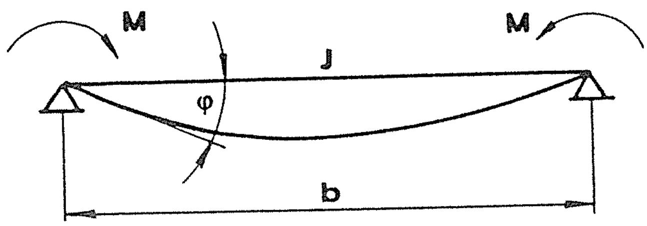
*Simple beam, inner moment at the other end* (Fig. 6)




$$\varphi = \frac{M \times b}{6E \times J}$$

Fig. 6 - Diagram for calculation of the angle of distortion.

*Simple beam, inner moments of the same value at both ends* (Fig. 7)




$$\varphi = \frac{M \times b}{2E \times J}$$

Fig. 7 - Diagram for calculation of the angle of distortion.

Three different operational conditions should be taken into consideration:

(i) *Normal operation (running conditions), rated load uniformly distributed on the car floor area.*

The crosshead beam is subjected to concentrated load $(Q+K) \times g_n$ in the middle of the span. Since the frame is symmetrical and also the load is located symmetrically to the vertical axis of the frame, inner moments at the ends of the crosshead beam will be identical ($M_1$) as well as inner moments at the ends of the safety plank ($M_2$).

Dimensions, moments of inertia of individual components, forces and inner moments are indicated in Fig. 8.

Equation for inner moment $M_1$ (equality of angles of distortion of the left end of the crosshead and the upper end of the uprights):

$$-\frac{(Q+K) \times g_n \times b^2}{16E \times J_1} + \frac{M_1 \times b}{2E \times J_1} = -\frac{M_1 \times l}{3E \times J_2} - \frac{M_2 \times l}{6E \times J_2}$$

Equation for inner moment $M_2$ (equality of angles of distortion of the left end of the safety plank and the bottom end of the uprights):

$$\frac{(Q+K) \times g_n \times b^2}{24E \times J_3} - \frac{M_2 \times b}{2E \times J_3} = \frac{M_2 \times l}{3E \times J_2} + \frac{M_1 \times l}{6E \times J_2}$$

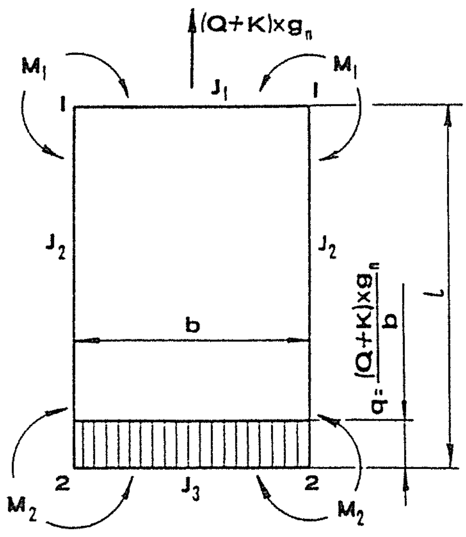



Fig. 8 - Dimensions, moments of inertia, forces and moments on individual parts of the frame.

By solution of the preceding equations resultant formulae for the inner moments $M_1$ and $M_2$ may be obtained:

$$M_1 = \frac{(Q+K) \times g_n \times b^2}{24} \times \frac{6l \times J_2 \times J_3 + 9b \times J_2^2 - 2l \times J_1 \times J_2}{l^2 \times J_1 \times J_3 + 2b \times l \times (J_1 \times J_2 + J_2 \times J_3) + 3b^2 \times J_2^2}$$

$$M_2 = \frac{(Q+K) \times g_n \times b^2}{24} \times \frac{4l \times J_1 \times J_2 + 6b \times J_2^2 - 3l \times J_2 \times J_3}{l^2 \times J_1 \times J_3 + 2b \times l \times (J_1 \times J_2 + J_2 \times J_3) + 3b^2 \times J_2^2}$$

Fig. 9 shows a diagram for all the parts of the car frame after they have been released and loads exerted on each of them. Due to the difference between $M_1$ and $M_2$ an inner force $X$ will be created, causing tension in the crosshead beam and pressure in the safety plank. The value of $X$ is given by the formula:

$$X = \frac{M_1 - M_2}{l}$$

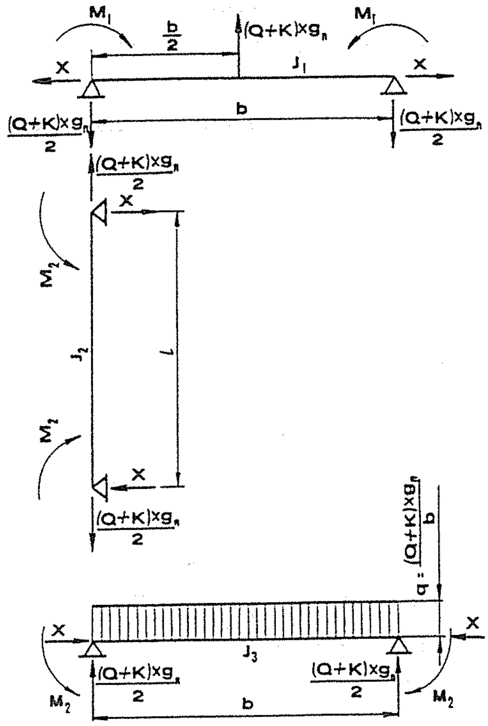



Fig. 9 - Forces and moments exerted on individual parts of the frame.

The bending moment along the car frame is illustrated in Fig. 10.

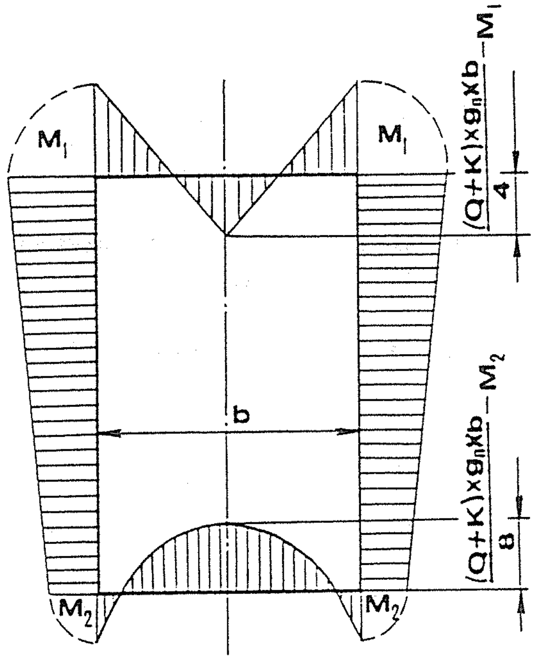



Fig. 10 - Bending moment along the car frame.

If the load were not assumed to be uniformly distributed on the car floor, then for the purpose of calculation it would be considered concentrated at a point located eccentrically (see Fig. 4), the eccentricity being in conformity with the class of loading. The calculation would be more complicated as the inner moments would be different at each corner, so that four equations would have to be written for four unknown moments.

(ii) *Safety gear operation*
In Fig. 11 the principal dimensions of all parts of the car frame, moments of inertia, forces and inner moments are indicated. The coefficient $\psi$ takes account of the dynamic force during the safety gear operation and can be calculated from the formula:

$$\psi = 1 + \frac{a}{g_n}$$

where $a$ is retardation during the safety gear operation (m/s²).

Uniform distribution of the load on the car floor has been assumed.

Two equations for two unknown moments $M_1$ and $M_2$ will be obtained:

$$-\frac{M_1 \text{ x } b}{2E \text{ x } J_1} = \frac{M_1 \text{ x } l}{3E \text{ x } J_2} - \frac{M_2 \text{ x } l}{6E \text{ x } J_2}$$

$$\frac{\psi \text{ x} (Q+K) \text{ x } g_n \text{ x } b^2}{24E \text{ x } J_3} - \frac{M_2 \text{ x } b}{2E \text{ x} J_3} = -\frac{M_1 \text{ x } l}{6E \text{ x } J_2} + \frac{M_2 \text{ x } l}{3E \text{ x } J_2}$$

Resultant moments are:

$$M_1 = \frac{\psi \text{ x} (Q+K) \text{ x } g_n \text{ x } b^2}{12} \text{ x } \frac{l \text{ x } J_1 \text{ x } J_2}{l^2 \text{ x } J_1 \text{ x } J_3 + 2b \text{ x } l \text{ x} (J_1 \text{ x } J_2 + J_2 \text{ x } J_3) + 3b^2 \text{ x } J_2^2}$$

$$M_2 = \frac{\psi \text{ x} (Q+K) \text{ x } g_n \text{ x } b^2}{12} \text{ x } \frac{2l \text{ x } J_1 \text{ x } J_2 + 3b \text{ x } J_2^2}{l^2 \text{ x } J_1 \text{ x } J_3 + 2b \text{ x } l \text{ x} (J_1 \text{ x } J_2 + J_2 \text{ x } J_3) + 3b^2 \text{ x } J_2^2}$$

Fig. 12 illustrates loads exerted upon individual parts of the car frame, Fig. 13 the bending moment along the car frame.

In comparison with (i) the inner force $X$ is given by a modified formula:

$$X = \frac{M_1 + M_2}{l}$$

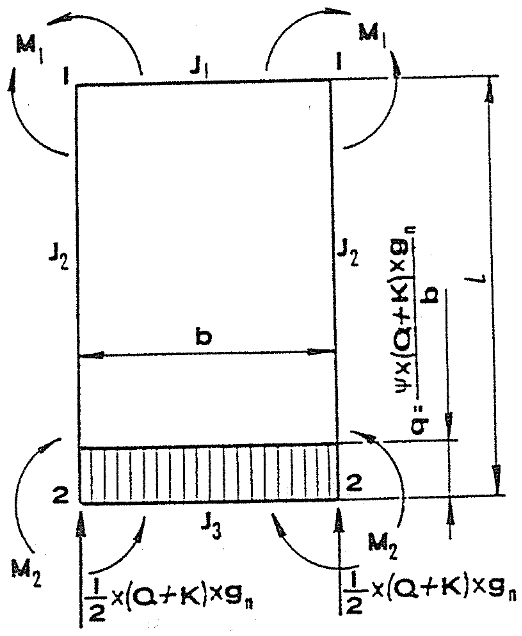



Fig. 11 - Dimensions, moments of inertia, forces and moments on all parts of the car frame.

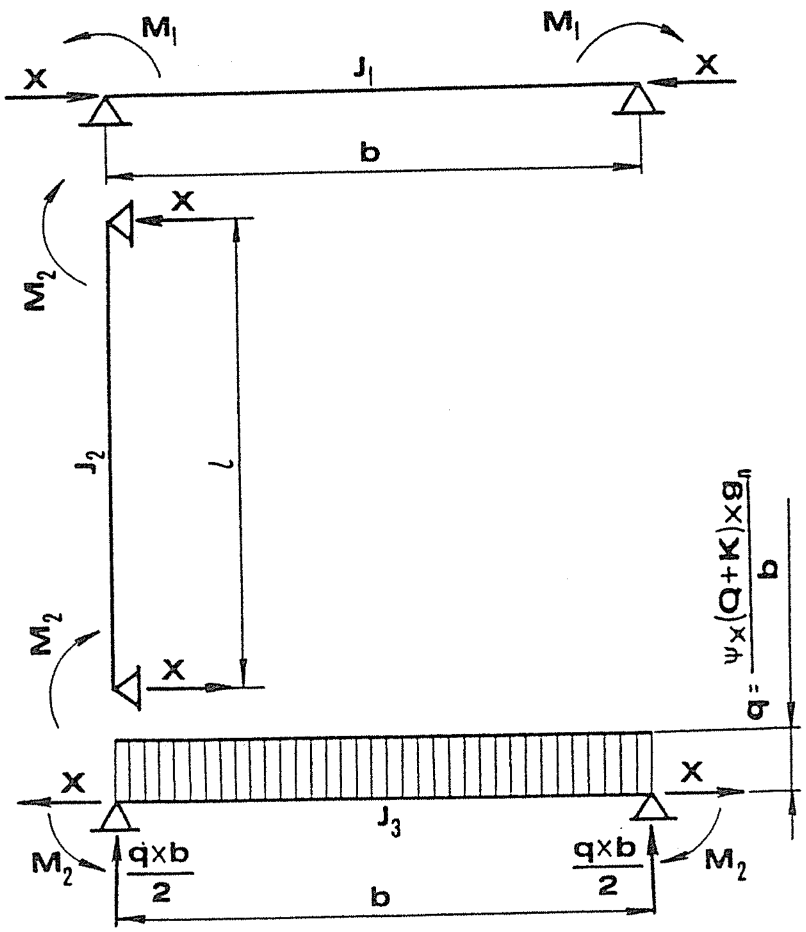



Fig. 12 - Forces and moments exerted on all parts of the frame.

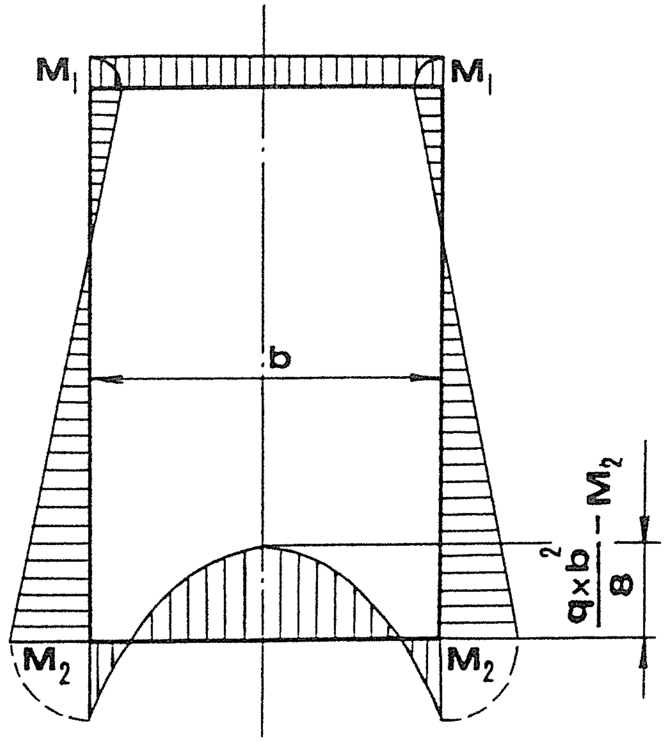



Fig. 13 - Bending moment along the car frame.

(iii) *Buffer engagement*
The case of one buffer located in the centreline of the car is shown in Fig. 14. The meaning of the coefficient $\psi$ is the same as in (ii). Uniform distribution of the load in the car is assumed; the buffer reaction force $F$ is given by the formula:

$$F = \psi \times (Q + K) \times g_n = (Q + K) \times (g_n + a)$$

Equations for the inner moments $M_1$ and $M_2$ are:

$$\frac{M_1 \times b}{2E \times J_1} = -\frac{M_1 \times l}{3E \times J_2} + \frac{M_2 \times l}{6E \times J_2}$$

$$-\frac{F \times b^2}{16E \times J_3} + \frac{F \times b^2}{24E \times J_3} + \frac{M_2 \times b}{2E \times J_3} = -\frac{M_2 \times l}{3E \times J_2} + \frac{M_1 \times l}{6E \times J_2}$$

From these equations formulae for $M_1$ and $M_2$ may be easily obtained.

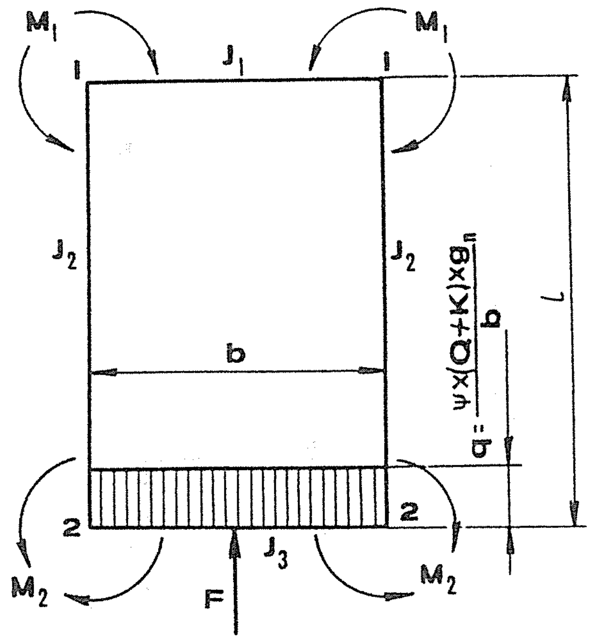



Fig. 14 - Dimensions, moments of inertia, forces and moments on the frame.

The loads exerted upon the frame components are shown in Fig. 15, the bending moment along the car frame is depicted in Fig. 16. The inner force $X$ is given by the same formula as in (ii), i.e.:

$$X = \frac{M_1 + M_2}{l}$$

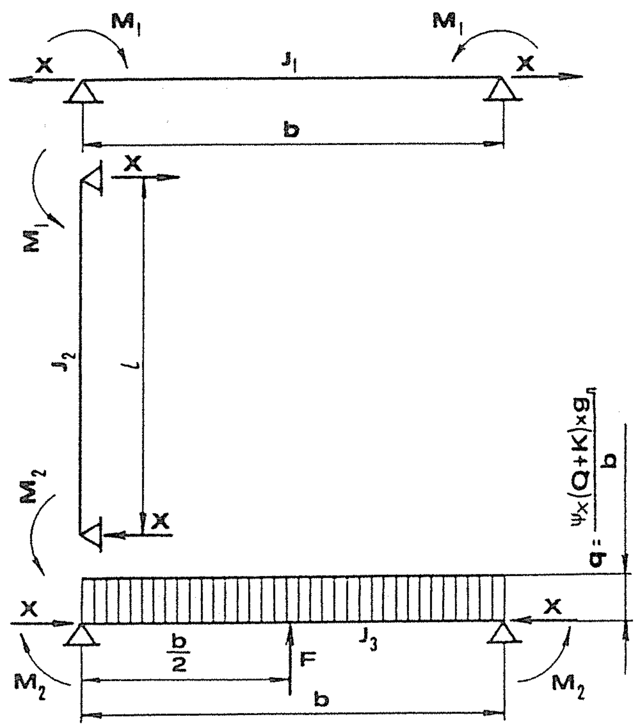



Fig. 15 - Forces and moments exerted on all parts of the frame.

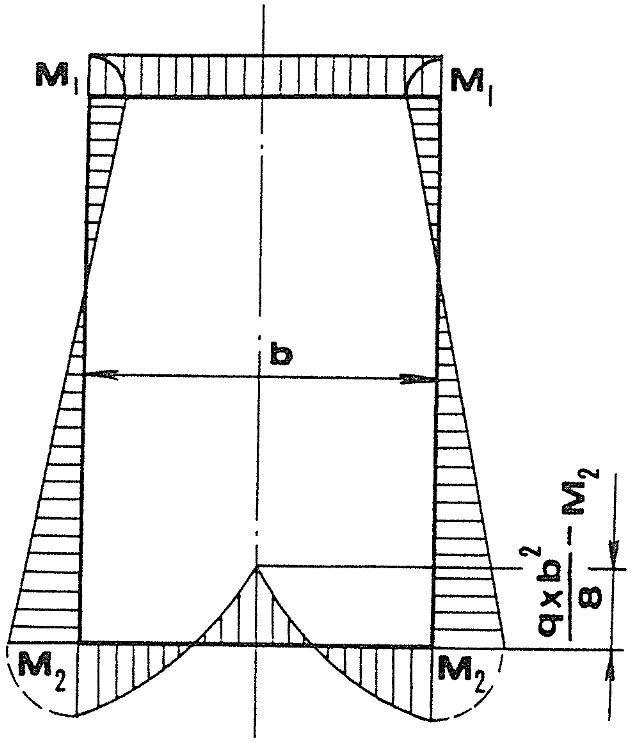



Fig. 16 - Bending moment along the car frame.

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**BIOGRAPHY:**

Lubomír Janovský has been employed as a Reader with the Czech Technical University, Faculty of Mechanical Engineering, Prague, Czech Republic. He is also an elevator and escalator consultant. He has been a foreign correspondent for *ELEVATOR WORLD* since 1978, a Vice Chairman of the Executive Board of IAEE and a member of the International Board of *ELEVATORI*. He gained his Ing. (Masters level) in Mechanical Engineering and his CSc. (doctorate) in Vertical Transportation, both from the Czech Technical University in Prague. He has written numerous books and papers on vertical transportation and materials handling, including *ELEVATOR MECHANICAL DESIGN*, published by Ellis Horwood Ltd. in 1987 (1st edition) and 1993 (2nd edition).